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METHODS AND COSTS OF MINING FERBERITE ORE AT THE COLD SPRINGS MINE, NEDERLAND, BOULDER COUNTY, COLO.[1]

By William O. Vanderburg[2]

INTRODUCTION

This paper describing the mining practices at the Cold Springs mine of the Wolf Tongue Mining Co. at Nederland, Colo., is one of a series of similar papers prepared by the Bureau of Mines on mining practices, methods, and costs at various mines in the United States.

The writer acknowledges the assistance of William Loach and William T. Todd, manager and mine superintendent of the Wolf Tongue Mining Co., respectively, in the preparation of this paper.

GENERAL

The Cold Springs mine of the Wolf Tongue Mining Co. is 3 miles east of Nederland, Colo., at an elevation of about 8,500 feet. Although the winters are sometimes severe, operations can be continued through the entire year without difficulty. The mine is in the central part of the Boulder County tungsten district, which comprises an area roughly 12 miles long and 3 miles wide. Nederland lies 17 miles southwest of Boulder; it is accessible from the latter place by stage over an excellent automobile road up Middle Boulder Canyon. Boulder is the most convenient railroad shipping point, and all mining supplies except timber are hauled to the mine from Boulder by automobile truck.

The relief of the district is rugged. Good spruce and pine timber is fairly abundant on the surrounding slopes. Round timber for use in the mine is all cut on company-owned land.

Electric power for mining is purchased from the Public Service Co. of Colorado under a schedule which varies according to the demand. The hydro-electric plant of the Public Service Co. is on Middle Boulder Creek about halfway between Nederland and Boulder.

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6673."

[2] Associate mining engineer, U. S. Bureau of Mines.

At the Cold Springs mine the ferberite ore is extracted by the cut-and-fill system of stoping. A high-grade product is maintained by selective mining, hand sorting, and cobbing. Operations are conducted on a small scale by an average of about 15 men.

HISTORY

In 1870, Sam P. Congor, in prospecting over the hills of Boulder County discovered a heavy dark mineral which occurred as "float." The true nature of the mineral was unknown to Congor and others and was called "hematite," "black iron," and "barren silver." The mineral was not known to be of commercial importance until many years later when W. H. Wanamaker, a partner of Congor's, returned from a prospecting trip in the Dragoon Mountains of Arizona where a similar material was found and determined to be an ore of tungsten. Keeping the matter secret, Congor in 1900 secured a lease on a property now known as the Congor mines which at that time was held under agricultural right. By the end of 1900 Congor had taken out about 40 tons of high-grade ore. From 1900 until 1915 mining of tungsten ores was carried on spasmodically, although interest in the district was kept alive and considerable surface prospecting done by trenches, adits, and shallow shafts.

Because of the abnormal demand for tungsten as an ingredient for high-speed tool steel during the World War, the price of tungsten rose to fantastic figures and the town of Nederland became the center for a "boom." From a town of few inhabitants it grew to a population of between 4,000 and 5,000, and Boulder County became one of the foremost tungsten-producing districts of the world. During this boom period a number of mines in the vicinity of Nederland attained depths ranging from 200 to 500 feet and produced considerable amounts of ore. The greatest depth attained in underground mining operations was 1,160 feet in the Congor mine. Where the natural topography permitted, as in Boulder Canyon, the mines were worked through adits. Some of the larger mines had power available for compressing air for drilling but most of the ore was mined by hand drilling. In some cases lessees worked from the outcrops by open-cut methods. Considerable placer tungsten was also produced.

After the war period a recession in the price of tungsten concentrates forced all the mines to close down. The enactment of the tariff of 1922 revived activity to a small extent several years later. Of the numerous tungsten mines that were active during the boom period the Wolf Tongue Mining Co. has shown the longest period of continuous production in subsequent years.

The Wolf Tongue Mining Co. has been operating in the Boulder district since 1904. The company is controlled by the Firth Sterling Co. of Pittsburgh, Pa.

GEOLOGICAL FACTORS INFLUENCING MINING

The geology of the Boulder district has been described by George and Crawford[3] and by Hess and Schaller.[4]

Ferberite (the tungstate of iron, $FeWO_4$) is the only tungsten ore of economic importance in the Boulder district, which is unique in that it contains the largest known deposits of ferberite in the world.

In the Cold Springs mine the ferberite is in lenses along vein fissures. The lenses vary in length from a few feet to a maximum of 200 feet, measured along the strike. The average length is about 80 feet. The width of the ore varies from a fraction of an inch to a maximum of 6 feet. The average width mined is from 8 to 10 inches. About 3 inches is the least width of ore that can be mined economically, at a price of $12 to $13 per unit of WO_3. In the narrow portions of the lenses the ore consists of high-grade ferberite intimately associated with fine-grained quartz, which is the principal gangue mineral in all the ferberite ores. In the wider portions of the ore lenses a common occurrence of the ore is as a series of stringers with alternate layers of barren country rock between the stringers. The country rock is predominantly granite which frequently is gneissoid in character. Very little replacement of the wall rock is evident along the ore shoots, and in general the walls of the ore lenses or stringers are sharply defined.

The average dip of the veins is about 70°. Locally sudden changes in dips are apt to occur. The width and mineralization of the lenses is generally more persistent along the dip than along the strike.

A peculiar characteristic of the ferberite ore in places is the brecciated condition of the vein filling. The brecciated mixture of small fragments of country rock and ferberite resembles peanut candy, so that this type of ore is popularly called "peanut" ore. Where the ferberite and quartz are intimately mixed in a cryptocrystalline aggregate, the ores are locally called "hornstone."

The walls of the veins are generally traversed by a series of intersecting planes of weakness, so that sloughing of the wall rock is liable to occur if openings of more than 6 feet are made along the dip. Openings of less than 6 feet usually have sufficient strength to support themselves without a great amount of sloughing during the short time they are exposed while mining is in progress.

The veins on the Cold Springs property are generally covered with a mantle of surface wash to an average depth of about 6 feet, although in several places the veins outcrop.

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[3] George, R. D., and Crawford, R. D., The Main Tungsten Area of Boulder, Colorado: Colo. Geol. Survey, 1st rept., 1908.

[4] Hess, Frank L., and Schaller, Waldemar T., Colorado Ferberite and the Wolframite Series: U. S. Geol. Survey Bull. 583, 1914, pp. 7-19.

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The vein filling in the ore lenses is invariably of good grade, and the country rock in close proximity to the veins is practically barren of ferberite. These factors, in conjunction with the relatively high value of the clean ferberite and the ease with which ore and waste are distinguished by visual inspection, affords an excellent opportunity for hand sorting and selective mining, both of which practices are in use at the Cold Springs mine.

The ores are fairly soft, so that a lens exposed on one side along the strike can be easily removed by moil and hand hammer, allowing a minimum of waste admixture with the ore.

PROSPECTING

In the early days prospecting in the district was done by tracing float ferberite to its source, by digging shallow test pits or trenches, by sinking shallow shafts on the veins, or by driving adits to intersect the veins at depth. The veins were prospected underground by drifting on them until an ore shoot was discovered. Occasional crosscuts into the walls were driven in search of parallel veins. Due to the erratic distribution of the ore shoots along the veins and the variable horizons on which the ore shoots occur, extensive prospecting from short level intervals is necessary. In general the granite is more favorable for the finding of ore than the other rocks of the district. Changes in direction of the vein either along the strike or the dip are usually accompanied by changes in the character of the mineralization. Vein intersections are considered favorable loci for the finding of ore shoots.

"Diamond" drilling is employed at the Cold Springs mine in order to reduce the expense of prospecting with the usual lateral underground workings. Instead of the regulation diamond bit with the standard equipment, the bits have been made with firthite as the cutting agent. Firthite is an extremely hard compound consisting of tungsten carbide cemented with cobalt under a very high temperature. In using the firthite bit the firthite is set directly in the end of core barrels, using Tobin bronze 1/8 inch thick. The firthite "diamonds" are brazed into the core barrel by an acetylene welding machine. In setting the firthite care must be exercised in brazing, as excessive heating would destroy its effectiveness. A complete firthite bit can be made up for a cost of about $75. Like diamonds the firthite can be reused; a single bit can be used over and over again by resetting the firthite. In 1931 the total footage drilled with the firthite bits at the Cold Springs mine was 1932 feet, at an average cost of $2.16 per foot. Indications are that this cost will be reduced to about $1.50 per foot in 1932 by a superior grade of firthite and a better understanding of its use. In 1931 the maximum footage drilled with a single bit without resetting the firthite was 18 feet. The average depth of the holes drilled was 75 feet. Core recovery has averaged about 80 per cent.

By setting the firthite directly in the end of the core barrel instead of in the standard diamond bit the cutting area is considerably reduced and the diameter of core is proportionately increased. With the standard diamond-drill bit formerly used the outside diameter of the diamond bit is 1-7/16 inches and the inside diameter 15/16 inch. By using the firthite core-barrel bit the diameter of the core is increased to 1-5/16 inches. The cutting areas of the diamond and firthite bits are, respectively, 0.93 and 0.27 square inch. In drilling fissured rock the lower-priced firthite is a better choice than the diamond because of the danger of losing the bit.

Prospecting with deep-hole hammer drills was also tried at the Cold Springs mine, but was found unsuitable for two reasons: (1) When the drill encountered ore, the cracks apt to be present in the vein would permit the ferberite, which slimes readily, to escape so that the sludge sample would not be representative of the vein material; (2) because of the brittleness of the ferberite in comparison with the hard waste rock, much of the ferberite would be ground to a fine powder and carried away in suspension in the drill water, and the resulting assay would be unreliable. In addition the deep-hole drill gave very little information as to the width or dip of any ore shoot encountered.

SAMPLING

Visual inspection of the working faces is depended upon to control the grade of the ore mined, as the ferberite is dark and readily distinguished from the light-colored gangue and country rock. One familiar with the ore can estimate the grade with sufficient accuracy for practical purposes.

Due to the occurrence of the ferberite in isolated shoots of varying dimensions no reliable estimates of ore reserves can be made.

DEVELOPMENT

The Cold Springs mine is entered by a 2-compartment shaft inclined at 71° that was driven about 40 feet in the footwall of the Cold Springs vein, the major vein of the mine. The shaft is 500 feet deep as measured on the incline, and the first three levels, driven by lessees, have been established at intervals of 50 feet. The remaining three levels have been driven at intervals of 100 feet, as measured along the incline.

The main shaft is timbered with 8 by 8 inch timber sets placed on 5-foot centers. The details of the shaft timbering are shown in Figure 1. The skipway compartment and the manway and pipe compartment are both 4 feet 8 inches by 5 feet in the clear. The ground through which the shaft is driven is solid, so that no lagging is required except near the surface.

Lateral workings total about 5 miles. Drifts and crosscuts are driven 5 by 7 feet in cross section. The ground varies so much in character that nothing approaching a standard round can be employed in drilling. Drills of the Leyner type mounted on columns are used with 1-inch hexagonal hollow steel and the standard 14° and 5° tapered bits.

All breaking is done with 1-1/8 by 8 inch sticks of 40 per cent strength gelatin dynamite. No. 8 detonators attached to triple-taped fuse are used.

Raises are built either with one or two compartments, each 3½ by 3½ feet in section. In the 2-compartment raises, one compartment is used as a manway and general service compartment while the other is used as an ore pass. The single compartment raises are used solely as ore passes.

All raises are cribbed with round pine timber varying from 4 to 8 inches in diameter and cut in two lengths of 8 feet 6 inches and 4 feet 6 inches. The details of timbering a 2-compartment cribbed raise are shown in Figure 2. A departure from the usual practice of placing dividers in a 2-compartment raise is employed at the Cold Springs mine (fig. 2). With an axe the ends of the dividers of round timber 3½ feet long are made wedge-shaped, to a thickness of about 2½ inches. The dividers are held in position between 7-foot lengths of quarter-round lagging nailed to the cribbing. A divider is placed by inserting one end at an angle in the slot formed by the quarter-round lagging and dropping the other end into the slot on the opposite side.

Very little time is required to place the cribbing or dividers, as there is no framing or fitting to be done underground. Single-compartment raises are built of the 4½ foot lengths of cribbing.

To provide a bearing in placing the round timbers, the ends of the cribbing are framed on one side with a dap 1 inch deep and 6 inches long. To prevent breaking the top cribbing in stope blasting, short round blocks are temporarily placed between the openings of two consecutive timbers.

Raises are built up through the waste filling as the stopes advance. No raises are driven through to the level above in advance of stoping operations for exploration or development, so that blasting solely for the raises is not practiced at the Cold Springs mine.

STOPING

At the Cold Springs mine all the ore mined is extracted by the horizontal cut-and-fill system in which the filling operation is carried on contemporaneously with the ore breaking. The factors which give this method preference over other methods such as open stoping or shrinkage are: (1) The occurrence of the ferberite in narrow, rich veins so that considerable waste must be broken to provide working space; (2) the walls are generally weak and require artificial support, which can be cheaply provided by the waste from selective mining and hand sorting in the stopes; (3) in milling, the higher-grade ferberite ores are at a premium, so that it is desirable to obtain as high grade a mine product as is consistent with economy; (4) the ferberite is easily recognized and fine breaking is not required to separate ore from waste; (5) by adequate supervision the cut-and-fill method allows practically complete extraction of the ore.

At the Cold Springs mine no attempt is made to produce a large tonnage of low-grade material; complete extraction of the ore with minimum waste dilution is emphasized rather than the gross tonnage broken, and in this respect the practice follows that ordinarily employed by lessees. Tonnage rather than grade of ore could not be made the dominant factor in mining because of the erratic distribution of the ore shoots. With rapid mining there would be periods where the mill would be idle due to the necessity of prospecting for additional orebodies.

The question of raising the grade of the ore by sorting is vital to the economics of mining in the Boulder district. It means the choice between a small yield of high-grade material or a much larger tonnage of low-grade material, an alternative which affects all the operations at the surface as well as underground.

After an ore shoot has been opened up by drifting, a cut-and-fill stope is started by taking a cut from the back of the drift to a height of 5 or 6 feet. In this work the ore is kept separate from the waste by drilling and blasting the waste separate from the ore, or by blasting ore and waste together and then separating them by hand sorting. Ore and waste are loaded separately into cars by hand shoveling with square-end shovels, and using sheet iron for shoveling plats. After the back cut has been taken the drift is stulled with 8 to 12 inch diameter round timbers placed on 5-foot centers between chutes and on 4-foot centers at the chutes and manways. On the footwall side the stulls are supported by hitches cut into the wall, and on the hanging-wall side by headboards if the wall is sufficiently firm, or else by posts if the hanging wall is weak. Between the chutes the stulls are lagged with round timber of 4 to 6 inch diameter.

As the average length of the ore shoots is less than 100 feet, access to a stope is afforded by a double-compartment raise at either end. Additional cribbed ore passes are started between the double-compartment raises at intervals varying from 25 to 30 feet center to center. The distance between chutes is governed by the most convenient distance for hand shoveling the ore and waste into the chutes. The ore is drawn from the ore passes through chutes equipped with plank bottoms inclined about 40° and ordinary plank gates sliding in cleats.

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The stope is advanced by successive cuts 4 to 6 feet high carried along the full length of the ore shoot. Nothing approaching a standard drill round is employed in drilling, as the character of the ground and the ore occurrences vary considerably. In general, two methods of breaking are employed, depending on the mode of occurrence of the ferberite. Where the ferberite is in a single band of rich ore, stripping is employed; the waste is carefully blasted first, ordinarily on the hanging-wall side, and allowed to drop into the fill; after leveling off the fill by hand, a sheet-iron shoveling platform is laid on top of the fill and the exposed ore carefully blasted down with small charges of explosive, or if sufficiently loose is taken down with hand moil and hammer. Where the ore and waste are too intimately associated to be removed separately, they are broken down together on the sheet-iron shoveling platform and the waste is sorted from the ore by hand.

The amount of waste obtained by stripping and hand sorting is more than enough to provide the waste fill. The excess waste is shoveled into the chutes separately from the ore and transported to the surface.

All raises are carried up as the stope is advanced. The cribbed chutes and manways are built up to a height of 3 or 4 feet above the level of the fill before each cut is taken along the back of the stope. The raise cribbing is not blocked against the solid rock but is held in place by large pieces of waste placed by hand around all sides. The waste placed around the sides of the cribbing is also effective in preventing the fine waste fill from entering the chute. If any changes in direction along the dip occur, the cribbing timbers are selected so that their difference in diameter will provide for change in the inclination of the raise.

Supplies are brought into the stopes by small electric hoists.

Of the total amount of material broken in stoping in 1931 about 70 per cent was discarded by stripping and hand sorting underground, about 15 per cent was rejected by hand sorting on the surface, and the remaining 15 per cent constituted the ore that was sent to the mill. A small amount of fine ferberite is lost in the waste fill, but with careful supervision and selected workmen who are accustomed to leasing practice on ferberite ores, the amount thus lost is practically negligible.

ADVANTAGES OF HAND SORTING AND SELECTIVE MINING AT COLD SPRINGS MINE

Breaking the ore separate from the waste in the stopes and hand picking waste from the ore both in the stopes and on the surface as practiced at the Cold Springs mine is advantageous in several ways. It reduces the cost of transportation of ore from the mine to the mill, and it increases the mill capacity as measured in the number of units of tungstic acid treated. Due to the pronounced distinction between ore and country rock no difficulty is experienced in sorting ore from waste by hand. Virtually no ferberite occurs

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locked up in the centers of large pieces of waste, so that there is little loss from this source. Hand sorting and selective mining are especially applicable at the Cold Springs mine because of the occurrence of the ferberite in narrow veins where considerable waste has to be mined with the ore to provide sufficient room for working the stopes.

It is evident in considering the foregoing factors that the problem of mining is not so much one of breaking a large tonnage but of saving the valuable material. It has been found preferable to take less out of a stope at a greater cost per ton removed. The problem of sorting is one wherein the ultimate aim is the maximum net profit from a given amount of ferberite in a deposit, while the variables involved are the cost of freight and milling, mining, sorting, and the value of the rejected waste. The advantages of hand sorting ferberite ores at the Cold Springs mine can best be illustrated by a cost analysis of the problem. The following data are based on 1931 operations and although some of the basic data are estimated they are reasonably accurate. Ultimate profits, rather than the cost per ton of ore hoisted and milled, are the basis of calculation.

	Average value per ton
Run-of-mine ore as broken, containing 0.9 per cent of WO_3 (WO_3 figured at $12 per unit)	$10.80
Sorted ore containing 5.72 per cent of WO_3 (tungstic acid figured at $12 per unit)	68.64
Waste rejected in sorting containing 0.025 per cent of WO_3 (tungstic acid figured at $12 per unit)	.30

Assume: X = the number of tons from which 1 ton of $68.64 ore can be sorted.
Y = the number of tons of waste thrown away for each ton of $68.64 ore obtained.

Then $68.64 + 0.30\,Y = 10.80\,X$

and $X - Y = 1$

$$\begin{array}{rrl} 10.80\,X & -\ 0.30\,Y & = 68.64 \\ -0.30\,X & +\ 0.30\,Y & = -.30 \\ \hline 10.50\,X & & = 68.34 \end{array}$$

Therefore $X = 6.51$ tons of run-of-mine ore broken for every ton of sorted ore sent to mill.
$Y = 5.51$ tons of waste discarded for every ton of sorted ore obtained.

The cost of sorting 1 ton of $68.64 ore from the run-of-mine product is $1.95. Expressed in another way, the sorting cost per ton of run-of-mine ore is $\frac{1.95}{6.51}$, or $0.30. The cost of mining 1 ton of run-of-mine ore is $2.34. The cost of transporting ore from the mine to the mill on contract is $1 per ton. The milling cost of run-of-mine ore is taken as $2.85 and the cost of milling the sorted product is $3.22 per ton.[5] The mill recovery on the unsorted ore is estimated at 80 per cent and the recovery on the sorted ore is 87 per cent.

The profit per ton of ore without sorting is shown in the following calculation:

		Per ton
Mill returns $10.80 x 0.80 (recovery)		$8.64
Costs:		
Mining	$2.34	
Transportation	1.00	
Milling	2.85	
Total direct cost	6.19	6.19
Profit per ton of run-of-mine ore without sorting		2.45

The profit obtained by sorting is shown in the following calculation:

		Per ton of sorted ore
Mill returns $68.64 x 0.87 (recovery)		$59.72
Costs:		
Sorting	$ 1.95	
Mining (6.51 tons at $2.34 per ton)	15.23	
Transportation	1.00	
Milling	3.22	
Total direct cost	21.40	21.40
Profit per ton of sorted ore		38.32
Equivalent profit on unsorted ore ($2.45 x 6.51)		15.95
Additional profit obtained by sorting		22.37

Therefore, the additional profit obtained by sorting as based on 1 ton of run-of-mine ore is $\frac{22.37}{6.51}$ or $3.44, and the total profit is $\frac{38.32}{6.51}$ or $5.89, as against $2.45 obtained without sorting.

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[5] Vanderburg, William O. Methods and Costs of Milling Ferberite Ore at the Wolf Tongue Concentrator, Nederland, Boulder County, Colo.: U. S. Bureau of Mines Information Circular (in preparation).

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The economical limit of sorting - namely, the amount which can be paid for sorting before the profit will fall below that which is obtained without sorting - is calculated as follows, where

$2.45 = profit per ton of run-of-mine ore without sorting
$3.44 = additional profit by sorting
$0.30 = cost of sorting per ton of run-of-mine ore $\left(\frac{1.95}{6.51}\right)$.

and X = the maximum amount which can be paid for sorting 1 ton of run-of-mine ore.

Then 2.45 = 3.44 + 0.30 - X
X = $1.29, or the economical limit which can be paid for sorting 1 ton of run-of-mine ore.

The foregoing analysis reflects the importance of sorting when dealing with narrow veins. It should be mentioned, however, that sorting to be effective requires careful supervision, as it may result in actual loss if not properly done.

In the above cost analysis of sorting it is assumed that the cost of mining per ton of run-of-mine ore is the same whether or not sorting is practiced. Actually, however, if the waste obtained from sorting were not utilized for support the cost of mining would be appreciably higher if all the run-of-mine material were sent to the mill, because of the necessity of providing support for the stopes.

UNDERGROUND TRANSPORTATION AND HOISTING

Ore and waste are transported underground in end-dump, plain-bearing, steel cars holding about 1,200 pounds each. The average tramming distance underground in 1931 was about 300 feet. Track consists of 12-pound rails placed on a grade of $\frac{1}{2}$ per cent and a gage of 18 inches. Ties are of round lagging, about 4 inches in diameter, cut into 3-foot lengths, and trimmed flat on one side.

At the shaft the cars are dumped over a pivoted pan chute directly into the skip having a capacity of about 2,400 pounds. Rails in the skipway compartment of the shaft consist of 4 by 6 inch timbers bolted lengthwise to the 8 by 8 inch footwall plates. Upon the 4 by 6 inch timbers 3 by 3 inch angle irons are bolted with countersunk screws to provide the track for the skip wheels.

Because of the small amount of material hoisted skip pockets are not considered essential.

At the surface the ore is dumped from the skip over an inclined bar grizzly with 1-inch openings. The fines pass into a bin and the coarse material goes onto a stationary sorting table. Wooden gates control the flow of ore from the grizzly onto the sorting table. All pieces of ore are sorted from the waste by hand and thrown into the ore bin. Large pieces of combined ore and waste are cobbed. The waste is shoveled into cars and hand trammed to the waste dump. Two sorters can sort and cob about 20 tons of hoisted material per 8-hour shift.

PUMPING AND VENTILATION

The amount of water pumped from the mine varies with the seasons from 65 to 200 gallons per minute. The water is pumped to the surface by two electric plunger pumps.

As the Cold Springs workings are linked to the surface by a number of interconnected shafts, the mine is well ventilated by natural means. Dead-end stopes are sometimes ventilated artificially with small direct-connected fans. The fan pipe for these small ventilating units consists of 8-inch galvanized-iron pipe.

LEASING PRACTICE

In the Boulder district a large part of the ferberite ores have been mined on a leasing system. At the Wolf Tongue properties the leasing practice in vogue when tungsten concentrates are marketable is to grant a lease on a block of ground for a period of one year with the usual understanding that it can be renewed as long as desired if the work accomplished is satisfactory. The Wolf Tongue Co. is under no obligations to purchase the ore produced by lessees. No leases have been given in recent years in the main Cold Springs mine workings.

When the lessee can dispose of the crude ores he produces, more than $4 per day can be made on a streak of ferberite not more than 1 inch wide. In mining the narrow seams the lessee first strips the hanging-wall waste and then removes the ore with a moil and single-jack. The ore is caught on a canvas sheet. As a premium is paid on the higher-grade crude ferberite ores the lessee strives to make at least two products; one containing from 30 to 50 per cent of tungstic acid and the other containing from 10 to 30 per cent of tungstic acid. Ores under 5 per cent of tungstic acid are usually roughly concentrated to a higher-grade product by hand jigging. By hand sorting rich ore a lessee may sometimes make as many as five different products containing varying percentages of tungstic acid. The royalty paid is 15 per cent on the crude ores delivered at the mill.

Mining supplies and cost of hauling are paid for by the lessee.

The prices paid for different grades of crude ores vary from time to time with market conditions. Table 1 gives the base schedule of prices paid for lease ore calculated on a base price of $10 per short-ton unit[6] of tungstic acid in concentrates. If the prevailing price is greater than $10 per unit the amount paid the lessee is proportionately increased. For example, if ferberite concentrates are salable at $11.50 per short-ton unit, the price paid for crude ores is increased 15 per cent above those given in the table.

Due to the high slime loss, crude ores containing less than 3 per cent of WO_3 are uneconomical to treat under the present demand for only the higher-grade concentrates. Even with the high-grade ores, although an extraction of about 90 per cent is obtained in milling, a part of this recovery is in the form of low-grade concentrate which is difficult to sell.

Table 1.- The Wolf Tongue Mining Co. schedule for Boulder County crude ferberite ores

WO_3, per cent	Price paid		WO_3, per cent	Price paid	
	Per pound of contained WO_3	Per ton of ore		Per pound of contained WO_3	Per ton of ore
1	$0.05	$ 1.00	31	$0.363	$225.06
2	.06	2.40	32	.368	235.52
3	.09	5.40	33	.374	246.84
4	.18	14.40	34	.379	257.72
5	.22	22.00	35	.385	269.50
6	.245	29.40	36	.39	280.80
7	.27	37.80	37	.396	293.04
8	.275	44.00	38	.401	304.76
9	.285	51.30	39	.407	317.46
10	.295	59.00	40	.412	329.60
11	.315	69.30	41	.418	342.76
12	.32	76.80	42	.423	355.32
13	.325	84.50	43	.429	368.94
14	.33	92.40	44	.434	381.92
15	.335	100.50	45	.44	396.00
16	.34	108.80	46	.44	404.80
17	.345	117.30	47	.44	413.60
18	.35	126.00	48	.44	422.40
19	.35	133.00	49	.44	431.20
20	.355	142.00	50	.44	440.00
21	.355	149.10	51	.44	448.80
22	.355	156.20	52	.44	457.60
23	.355	165.30	53	.445	471.70
24	.355	170.40	54	.455	491.40
25	.357	178.50	55	.46	506.00
26	.358	186.16	56	.47	526.40
27	.358	193.32	57	.475	541.50
28	.36	201.60	58	.485	562.60
29	.36	208.80	59	.49	578.20
30	.363	217.80	60	.50	600.00

NOTE: The above schedule of prices is for crude tungsten ores delivered at the Wolf Tongue mill, Nederland, Colo., in ton and less-than-ton lots. This schedule is subject to change without notice and does not apply to any milled ores such as concentrates containing under 52 per cent of WO_3.

In lots valued at less than $50 a charge of $3 will be made for sampling and assaying; otherwise, no charge will be made.

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[6] A unit as applied to tungsten ores is 1 per cent of a ton of tungsten trioxide (WO_3). Thus a short-ton unit is 20 pounds of WO_3, a long-ton unit is 22.4 pounds of WO_3, and a metric-ton unit is 22.046 pounds of WO_3.

MINING COSTS

All mine labor was paid at the rate of $4 per day of 8 hours in 1931.

The costs of mining in 1931 amounted to $17.17 per ton of sorted ore produced. Table 2 summarizes the mining costs in dollars, and Table 3 in units of labor, power, and supplies. Due to the uncertain character of the deposits, mining costs are subject to considerable fluctuation from year to year. In mining the Boulder district ferberite ores the dead work is unusually large in proportion to the ore developed, because of the erratic distribution of the ore shoots. Under such a condition the development of a large tonnage of reserve ore is next to impossible. It is safe to say that although the Wolf Tongue Mining Co. was operated in the district for over 25 years, at no time during this period has there been sufficient positive ore developed to last more than half a year. Experience has demonstrated, however, that with sufficient development work and prospecting, additional ore shoots will be found.

In general, the cost of mining ferberite ores in the Boulder district is higher than the cost of mining deposits that can be systematically developed well in advance of mining operations.

To those accustomed to low mining costs the costs given in Table 2 appear abnormally high. Three factors must be considered in a comparison of the mining costs at the Cold Springs mine with costs elsewhere: (1) The Cold Springs mine is a small-tonnage operation; (2) the material produced at the mine is in reality a concentrate made by selective mining and hand sorting; and (3) a larger amount of development and prospecting is required than in usual mining practice.

Table 2.- Summary of costs

Name of mine: Cold Springs Period covered: 8 months of 1931.
Tons of ore recovered: 1125. Mining method: Cut-and-fill.

Underground costs per ton of sorted ore recovered

	Labor	Supervision	Air drills, steel, and compressed air	Power	Explosives	Timber	Other supplies	Tota
Development	$2.204	$1.008	$0.933	$0.738	$0.483	$0.651	$0.252	$6.2
Mining	1.636	.672	.622	.494	.323	.432	.170	4.3
Tramming and hoisting	.356	-	-	.616	-	-	.030	1.0
General underground and surface expense	3.840	-	-	-	-	.089	.513	4.4
Compensation insurance	1.110	-	-	-	-	-	-	1.11
Total	9.146	1.680	1.555	1.848	0.806	1.172	0.965	17.1

NOTE: Direct operating costs only are represented. Office expense, capital expense, taxes and insurance, marketing, carrying charges on unsold concentrates, and the like are not included.

Table 3.- Summary of costs in units of labor, power, and supplies

Name of Mine: Cold Springs. Period covered: 8 months of 1931.

Tons of ore recovered: 1,125. Mining method: Cut-and-fill.

		Development	Mining	Total
A. Labor (per ton of ore recovered):				
Ore sorting	man-hours	-	3.84	3.84
Hoisting	do	-	1.92	1.92
Blacksmithing	do	1.15	0.77	1.92
Tramming	do	-	0.71	0.71
Shoveling	do	0.93	0.61	1.54
Breaking	do	1.83	1.24	3.07
General	do	1.83	1.24	3.07
Supervision	do	1.15	0.77	1.92
Total per ton of ore recovered	do	6.89	11.10	17.99
Average ore recovered per man-shift, total labor, tons				0.445

B. Power and Supplies (per ton of ore recovered):

Explosives:	1 1/8 by 8 inch sticks, 40 per cent L.F. gelatin dynamite.	lbs.	4.49
Timber:	Cribbing 4 to 8 inches in diameter, 16 feet long	linear feet	26.7
	Lagging 3 to 4 inches in diameter, 16 feet long	do	12.3
	Stulls 8 to 12 inches in diameter, 12 feet long	do	3.3
	Sawed stock	board feet	4.4
Power:	Total	kilowatt-hours	61.6

Air compression	29.3	do
Hoisting	12.3	do
Pumping	18.5	do
Lighting and ventilation	1.5	do
Total	61.6	do

C. Proportion of total direct cost:

Labor	per cent	63
Power and supplies	do	37

376

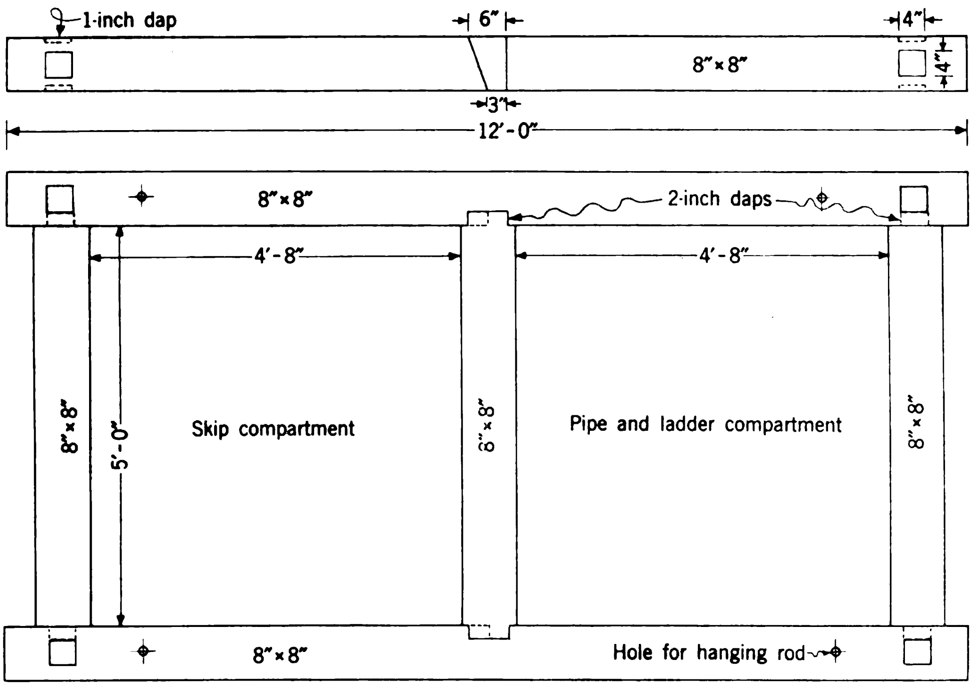

Figure 1.—Details of shaft timbering

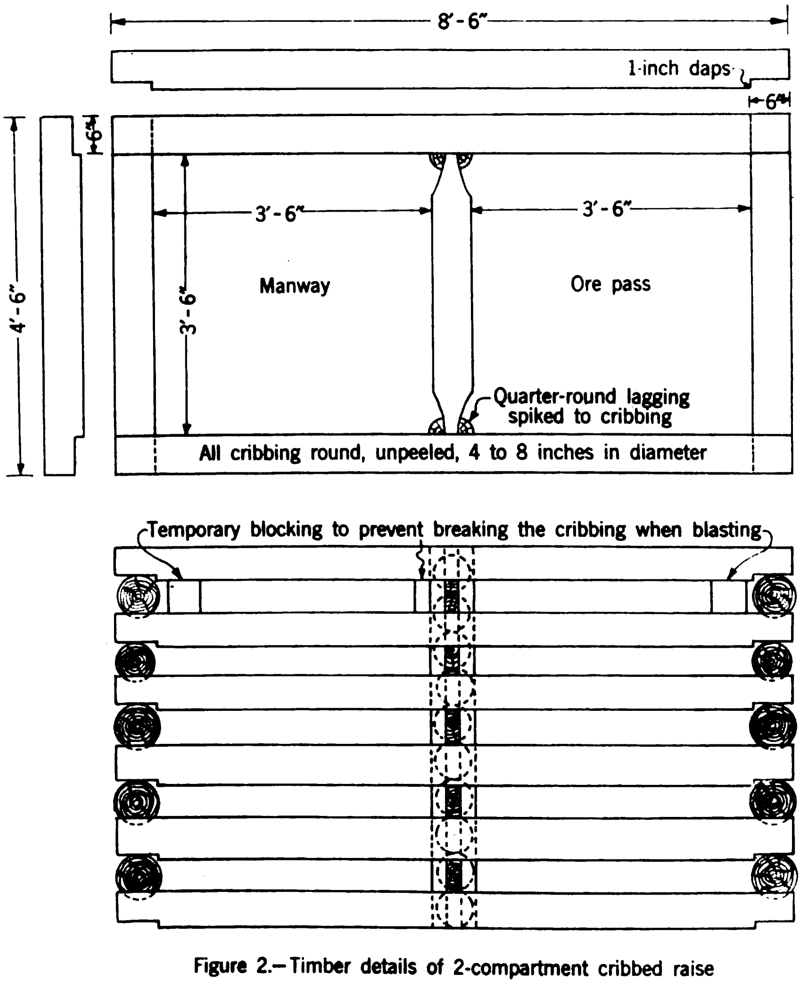
8'-6"
1-inch daps
6"
6"
4'-6"
3'-6"
3'-6"
3'-6"
Manway
Ore pass
Quarter-round lagging spiked to cribbing
All cribbing round, unpeeled, 4 to 8 inches in diameter
Temporary blocking to prevent breaking the cribbing when blasting

Figure 2.—Timber details of 2-compartment cribbed raise